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# Factor analysis of projected carbon dioxide emissions according to the IPCC based sustainable emission scenario in Turkey

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ABSTRACT

The Greenhouse gas emissions one of the hot topics all around the world which are causing climate change. In the face of anthropogenic climate change, increasing the carbon dioxide emissions as well as the development of Turkey seems to be a serious challenge for the success of global carbon dioxide emission reduction efforts. A decomposition analysis of historical and projected carbon dioxide emissions from fossil fuel combustion of Turkey has been investigated by using the Logarithmic Mean Divisia Index technique by considering in particular carbon intensity, energy mix, energy intensity, affluence and population effects. The projected data have been obtained from International Panel on Climate Change based sustainable emission scenario. The results show that the all effects on carbon dioxide emissions were positive for historical evaluation. On the other hand, carbon intensity, energy mix and energy intensity effects on carbon dioxide emissions were negative while affluence and population effects were still positive for projected evaluations. Therefore, decision makers should be reconsider the carbon dioxide emissions reduction targets and some related policies.



## 1. Introduction

Carbon dioxide ($CO_2$) emissions due the fossil fuel combustion are the most important cause of global warming and climate change in the World. Greenhouse Gas (GHG) emissions in the world account for 76% of $CO_2$ emissions [1]. The total $CO_2$ emissions annual growth rates of Turkey and World for the time period 1971–2014 were about 4.6% and 2.0% respectively [2]. In the face of anthropogenic climate change, increasing the $CO_2$ emissions as well as the development of Turkey seems to be a serious challenge for the success of global $CO_2$ emission reduction efforts.

Several scenarios based on the IPCC (Intergovernmental Panel on Climate Change) are used to calculate quantity of global GHG emissions and the dimensions of climate change in the future. These scenarios include various assumptions to predict GHG emissions and climate change over time. The emissions scenarios of the IPCC quantifying global GHG emissions and temperature changes over the world up to the year 2100 have significantly changed during their evolution from the First [3], Second [4], Third [5], Fourth [6] and Fifth Assessment Report [7].

Within the IPCC-based scenarios, it is assumed that the transition to sustainability in the B1 scenario family stated in the Special Report Emissions Scenarios (SRES) is almost complete by the end of the 21st century [8]. The scenario family that best represents sustainable development within SRES scenarios is B1 [5]. Furthermore, when comparing SRES scenarios with Representative Concentration Pathways (RCPs) scenarios, RCP4.5 in RCPs is in parallel with scenario B1 in SRES [7,9].

The high increase in $CO_2$ emissions of Turkey depends on the use of fossil fuels intensively with the economic growth of Turkey. In this case, while the $CO_2$ emissions in the world are declining, suitable strategies for low carbon emissions should be established without sacrificing Turkey's development needs. In this case, Turkey's total energy use for the future, will require increasing the share of renewable energy sources.

In this paper, to determine those strategies for Turkey in the future, $CO_2$ emissions for the time periods 1971–2014 (historical), 2015–2060 (projected) and their driving forces by using the Kaya decomposition analysis [10–13], considering in particular carbon intensity, energy mix, energy intensity, affluence and population effects have been investigated. The projected data of Turkey for $CO_2$ emissions, total primary fossil energy supply, the total primary energy supply, the total gross domestic product purchasing power

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parity and the population for the time period of 2015–2060 have been determined from the annual average growth rates of IPCC-SRES-B1-MESSAGE data [14] and also the historical data of Turkey [2,15].

## 2. Materials and methods

### 2.1. Decomposition analysis

The total $CO_2$ emission can be expressed as an extended Kaya identity which is a useful tool to decompose the total carbon emission as a product of five variables:

$$(CO_2) = (CO_2/TPFES)(TPFES/TPES)(TPES/GDPPPP) \times (GDPPPP/P)(P) \quad (1)$$

Where *TPFES* is the total primary fossil energy supply, *TPES* is the total primary energy supply, *GDPPPP* is the total gross domestic product purchasing power parity and *P* is the total population: $CI = (CO_2/TPFES)$ is the carbon intensity of fossil energy use, $EM = (TPFES/TPES)$ is the share of total primary fossil energy supply in total primary energy supply, $EI = (TPES/GDPPPP)$ is the energy intensity of economic activity, $A = (GDPPPP/P)$ is the per capita GDPPPP (affluence) and $(P)$ is the population.

The change of $CO_2$ emission between a base year (t) and a target year (t+Δt), denoted by $(\Delta CO_2)$, can be defined as a function of the variables namely: the change in the carbon intensity effect $(CIE)$, the change in the energy mix effect $(EME)$, the change in the energy intensity effect $(EIE)$, the change in the affluence effect $(AE)$ and the change in the population effect $(PE)$ can be written as follow:

$$(\Delta CO_2) = (CO_2)^{t+\Delta t} - (CO_2)^t = CIE + EME + EIE + AE + PE \quad (2)$$

Two popular conventional decomposition methods, i.e. refined Laspeyres method [11,16–18] and logarithmic Mean Divisia Index (LMDI) method [19–22]. In this study, LMDI method has been used in the analysis instead of refined Laspeyres method. Since LMDI method isn't contain residual terms in the analysis [23].

According to the complete decomposition model given by LMDI method for each effect in Eq. (2) can be computed as follows:

$$CIE = \frac{(CO_2)^{t+\Delta t} - (CO_2)^t}{ln\left((CO_2)^{t+\Delta t}/(CO_2)^t\right)} ln\left(CI^{t+\Delta t}/CI^t\right) \quad (3)$$

$$EME = \frac{(CO_2)^{t+\Delta t} - (CO_2)^t}{ln\left((CO_2)^{t+\Delta t}/(CO_2)^t\right)} ln\left(EM^{t+\Delta t}/EM^t\right) \quad (4)$$

$$EIE = \frac{(CO_2)^{t+\Delta t} - (CO_2)^t}{ln\left((CO_2)^{t+\Delta t}/(CO_2)^t\right)} ln\left(EI^{t+\Delta t}/EI^t\right) \quad (5)$$

$$AE = \frac{(CO_2)^{t+\Delta t} - (CO_2)^t}{ln\left((CO_2)^{t+\Delta t}/(CO_2)^t\right)} ln\left(A^{t+\Delta t}/A^t\right) \quad (6)$$

$$PE = \frac{(CO_2)^{t+\Delta t} - (CO_2)^t}{ln\left((CO_2)^{t+\Delta t}/(CO_2)^t\right)} ln\left(P^{t+\Delta t}/P^t\right) \quad (7)$$

### 2.2. Data

The historical data for $CO_2$ emissions, *GDPPP* and *POP* for the time period 1971–2014 were collected from International Energy Agency [2]. Whereas, *TPFES* and *TPES* were collected for the same time period from Republic of Turkey Ministry of Energy and Natural Sources-General Directorate of Energy Affairs [15]. *TPFES* was determined by summing the energy derived from each fossil fuel sources: coal, natural gas and oil. According to the data used in this study for the total $CO_2$ emissions, *TPFES*, *TPES*, *GDPPP* and *POP* annual average growth rates of Turkey for the time period 1971–2014 were about 4.6%, 4.8%, 4.2%, 4.1% and 1.7% respectively [2 15].

Within the IPCC-based scenarios, the scenario family that best represents sustainable development within SRES scenarios is B1 [5]. The projected $CO_2$ emissions, *TPFES, TPES GDPPP and POP* data for B1 scenario are available on the SRES website of the MESSAGE model developed by the International Institute for Applied System Analysis (IIASA) for the OECD90 region, where Turkey is also located in this region. These data are presented within 10-year time-period in Table 1 [14]. And the annual average growth rates of $CO_2$ emissions, *TPFES*, *TPES GDPPP* and *POP* given in Table 1 have been calculated as presented in Table 2.

As can be seen from Table 2, IPCC-SRES-B1-MESSAGE scenario data support the increase the percentage of renewable energy resources in total primary energy supply in addition to the tendency to reduce the use of coal, oil and natural gas.

By assuming that Turkey will continue to develop in the context of sustainability the $CO_2$ emissions, *TPFES*, *TPES GDPPP* and *POP* values of Turkey for the period of 2015–2060 have been calculated by using the annual average growth rates of $CO_2$ emissions, *TPFES*, *TPES GDPPP* and *POP* given in Table 2 and also the historical data of Turkey [2,15]. According to the calculated data in this study for the total $CO_2$ emissions, *TPFES*, *TPES*, *GDPPP* and *POP* annual average growth rates of Turkey for the time period 2015–2060 were about −1.4%, −1.1%, −0.2%, 1.5% and 0.2% respectively.

**Table 1**
IPCC-SRES-B1-MESSAGE data for OECD90 region.

| Variable | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 |
|---|---|---|---|---|---|---|
| Population (million) | 965 | 1007 | 1043 | 1069 | 1081 | 1084 |
| GDPPPP Trillion (1990 prices) | 22,441 | 28,082 | 33,259 | 38,271 | 43,554 | 48,468 |
| Coal (EJ) | 35,6 | 36,5 | 30,5 | 13,7 | 4,9 | 3,7 |
| Oil (EJ) | 82,7 | 73,2 | 62,3 | 52,7 | 44 | 35,7 |
| Natural Gas (EJ) | 56,9 | 67,5 | 79,6 | 87,4 | 83,5 | 74,7 |
| Total Primary Energy (EJ) | 201,7 | 213,4 | 215,1 | 206,6 | 197,9 | 192,3 |
| Fossil Fuel $CO_2$ (GtC) | 3396 | 3350 | 3130 | 2604 | 2159 | 1845 |

**Table 2**
Calculated annual growth rates for B1-MESSAGE data for OECD90 region.

| Variable | 2010–2020 | 2020–2030 | 2030–2040 | 2040–2050 | 2050–2060 |
|---|---|---|---|---|---|
| POP | 0,00426 | 0,00351 | 0,00246 | 0,00112 | 0,00028 |
| GDPPPP | 0,02243 | 0,01692 | 0,01404 | 0,01293 | 0,01069 |
| Coal | 0,00250 | −0,01796 | −0,08003 | −0,10,282 | −0,02809 |
| Oil | −0,01220 | −0,01612 | −0,01673 | −0,01804 | −0,02090 |
| Natural Gas | 0,01708 | 0,01649 | 0,00935 | −0,00456 | −0,01114 |
| TPES | 0,00564 | 0,00079 | −0,00403 | −0,00430 | −0,00287 |
| $CO_2$ | −0,00135 | −0,00682 | −0,01840 | −0,01875 | −0,01570 |

### 2.3. Calculation

Eqs. (2)–(7) presents the required formulas for decomposition analysis. A programme in MATHEMATICA [24] has been developed to do the calculations in this paper. $CO_2$ emissions for the time periods 1971–2014 (historical), 2015–2060 (projected) and their driving forces by using the Kaya decomposition analysis considering in particular *CIE, EME, EIE, AE* and *PE* have been calculated within 10-year time periods. The calculated decomposition analysis results for the time periods 1971–2014 (historical), 2015–2060 (projected) within 10-year time periods have been presented in Fig. 1 and Fig. 2 respectively. And the calculated decomposition analysis results for the whole time periods 1971–2014 (historical) and 2015–2060 (projected) has been also presented in Fig. 3.

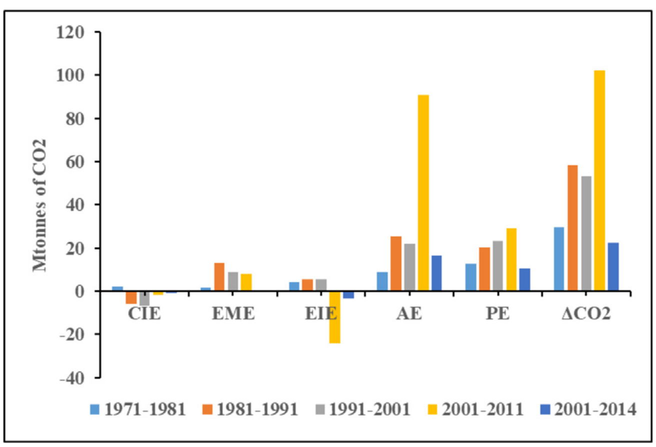


**Fig. 1.** Decomposition analysis for the time period 1971–2014 within 10-year.

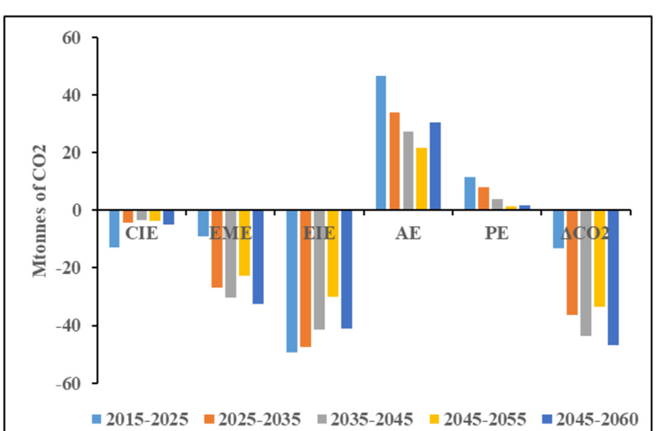


**Fig. 2.** Decomposition analysis for the time period 2015–2060 within 10-year.

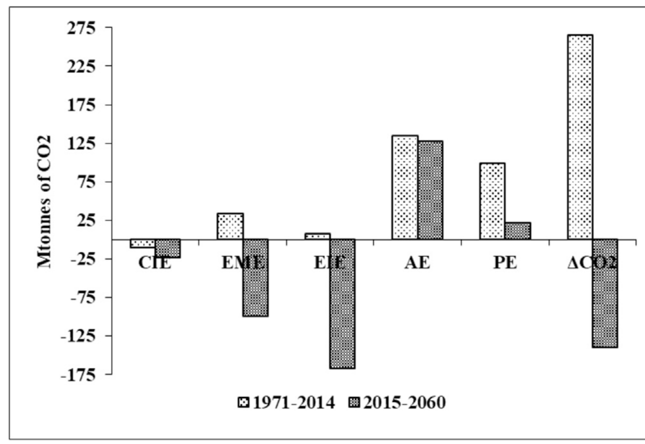


**Fig. 3.** Decomposition analysis for the whole time periods 1971–2014 and 2015–2060.

## 3. Results and discussions

### 3.1. Historical results

According to the results given in Fig. 1, the affluence and population effects were the two biggest contributors to $CO_2$ emissions for all study periods. The carbon intensity effect was accelerated to decrease in $CO_2$ emissions for all periods expect the period 1971–1981.

The energy mix and energy intensity effects were accelerated to increase in $CO_2$ emissions for all periods expect the period 2001–2014. The affluence and population effects were accelerated to increase in $CO_2$ emissions for all periods.

### 3.2. Projected results

The energy intensity effect was the biggest contributor to $CO_2$ emissions for all study periods. The carbon intensity, energy mix and energy intensity effects were accelerated to decrease in $CO_2$ emissions for all periods. While the affluence and population effects were accelerated to increase in $CO_2$ emissions for all periods (see Fig. 2).

### 3.3. Comparison of historical and projected results

According to the results given in Fig. 3, the calculated $CO_2$ emissions in the historical period was 265.4 Mtonnes of $CO_2$. While the calculated $CO_2$ emissions in the projected period was −139.9 Mtonnes of $CO_2$. The carbon intensity effect was accelerated to decrease in $CO_2$ emissions for both historical and projected periods approximately in the same amount. The energy mix and energy intensity effects were accelerated to increase in $CO_2$ emissions for historical period. Same effects were accelerated to decrease in $CO_2$ emissions for projected period. The affluence and population

effects were accelerated to increase in $CO_2$ emissions for both historical and projected periods. But the acceleration in $CO_2$ emissions in historical period is much higher than the projected period.

### 3.4. Discussions

The carbon intensity effect is a measure of the amount of $CO_2$ associated with each unit of primary fossil energy used. $CO_2$ emissions change by energy source, with coal being the most carbon intensive fuel, followed by oil and natural gas. According to the results of this study, the carbon intensity effect was accelerated to decrease in $CO_2$ emissions for both historical and projected periods approximately in the same amount. According to those results, the carbon intensity effect is not as important as affluence and population effects.

Based on the calculation, the energy mix and energy intensity effects were accelerated to increase in $CO_2$ emissions for historical period. Same effects were accelerated to decrease in $CO_2$ emissions for projected period. So if Turkey will act according to sustainable development scenario (B1) envisaged by the IPCC for $CO_2$ emissions, the energy mix and energy intensity effects will be accelerated to decrease in $CO_2$ emissions for projected period. The affluence and population effects were accelerated to increase in $CO_2$ emissions for both historical and projected periods. But the acceleration in $CO_2$ emissions in historical period is much higher than the projected period. So if Turkey will act according to sustainable development scenario (B1) envisaged by the IPCC for $CO_2$ emissions, the affluence and population effects will be accelerated to decrease in $CO_2$ emissions in considerable amount for projected period.

The use of renewable energy resources (except hydro) for electricity generation of Turkey had begun after the 2000s. In 2000, Turkey's electricity generation from renewable energy sources (geothermal, wind, solar, waste and waste heat) was 0,3%. This percentage was reached to 1,9%, 8,7% and 10% in 2010, 2016 and 2017 respectively [25,26]. If the same growth rates continue for electricity generation from renewable energy sources in the future, this will be significantly contributing to the reduction of $CO_2$ emissions in Turkey.

On the other hand, the use of wind in the electricity production of Turkey is much higher compared to other renewable energy sources (especially solar). If the use of PV systems in the electricity production of Turkey increases in the future, the percentage of increase in total renewable energy usage in the total production of electricity may increase within higher growth rates in the electricity production of Turkey. The increasing usage of PV systems in the electricity production of Turkey depend on technological development on PV systems. Technological developments on PV systems show that this will be possible.

For this purpose, Turkey should continue to increase investment and promote for development of renewable energy technologies and usage of them in electricity generation. Acceleration of this processes will contribute to the reduction of $CO_2$ emissions in Turkey as in the B1 scenario in the future.

Besides these, renewable energy cooperatives provide a significant contribution to generation of electricity in the place where it is consumed, the use of local resources by local people, providing employment, providing local development, positive effects on the environment and reduce energy dependency [27]. RESCOOP is the European federation of renewable energy cooperatives. They are a growing network of 1250 European energy cooperatives and their 1000000 citizens who are active in the energy transition. In large percentages, renewable energy sources, wind, PV and biomass are using as sources of electricity generation in the largest of those cooperatives [28]. Therefore, government should be support to the renewable energy cooperatives in Turkey. Supporting of renewable energy cooperatives will contribute greatly to the use of renewable energy sources in electricity generation of Turkey.

## 4. Conclusions

To better understand the $CO_2$ emissions in Turkey, the complete decomposition method was used to analyse the factors that influence the changes in $CO_2$ emissions for the past (1971–2014) and projected (2015–2060) periods by using the LMDI method. The five factors, including carbon intensity, energy mix, energy intensity, affluence and population effects, led to changes in $CO_2$ emissions of Turkey.

In the analysis of historical $CO_2$ emissions of Turkey, the main drivers for the growth of $CO_2$ emissions were affluence and population effects. The same factors have been shown a positive impact on projected $CO_2$ emissions of Turkey, but their values have been greatly reduced.

Based on the results of this study, if Turkey will act according to sustainable development scenario (B1) envisaged by the IPCC for $CO_2$ emissions, $CO_2$ emissions of Turkey will be decreased in considerable amount. Sustainable development scenario (B1) has two fundamental dimensions namely environmental protection and sustainable supply of resources in the long term, is reliable, adequate and affordable. Therefore, the overall objectives of energy-related policies should ensure sufficient, reliable and affordable energy supplies to support economic and social development, while protecting the environment.

The percentage of total fossil fuels (natural gas, hard coal and lignite) in installed capacity of Turkey is about 48% in 2017 [25]. And the percentage of renewable energy sources (geothermal, wind, solar, waste and waste heat) in installed capacity of Turkey is about 10% in 2017 [26]. Turkey imports of fossil fuels (natural gas, hard coal) are over 90% [15] and also fossil fuel based energy systems are not sustainable from the environmental perspectives. Thus, renewable energy percentages in installed capacity should be increased in the future.

The findings of this paper can help those decision makers reconsider their $CO_2$ emission reduction targets to make appropriate policies to apply sustainable development scenario (B1) envisaged by the IPCC for $CO_2$ emissions.

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